RESEARCH DEPARTMENT

THE USE OF OVERHEAD POWER LINES TO PROVIDE A V.H.F. BROADCASTING SERVICE

Report No. E-076

(1962/7)

THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

ERRATUM

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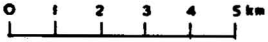

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(1962/7)

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SUMMARY

The provision of an adequate television or v.h.f. f.m. service in a mountainous area presents considerable difficulty since a large number of low-power relay stations is required. A possible alternative is the use of existing over-head power lines for both the transmission and radiation of the services throughout an area. In this report, the service area which could be obtained by the use of power lines is assessed and is compared with that obtainable with conventional transmitting stations. It is concluded that the use of radiation from power lines cannot be ruled out as impractical and that it would be advisable to carry out experiments to check the theoretical conclusions.

1. INTRODUCTION

Power lines have been used in some parts of the world to broadcast low- and medium-frequency transmissions to remote rural areas. It has been suggested that it might be possible to use the same method in this country to carry v.h.f. television and sound services to areas which would be difficult to cover economically using conventional low-power relay stations.

Overhead power lines could be used as radiators to propagate a v.h.f. service, conventional aerials being used for reception; alternatively, individual houses could be fed viâ their own electricity supply. In the latter arrangement, however, large numbers of inductors and capacitors would be required for isolating purposes and in addition, reception might be subject to severe interference from electrical machinery. The relatively high attenuation in the low-voltage cables would also be a disadvantage. Consequently this method of feeding is not thought to be practicable, and no further consideration is given to it in this report.

In an alternative method the radio-frequency currents would be confined to the high-voltage overhead lines serving the locality. Losses would be much smaller, and comparatively few isolating inductors and capacitors would be required.

The overhead lines from a substation to rural distribution points usually operate at a voltage of 11 kV, the lines being supported at a height of about 23 ft (7 m) on wooden poles, which are about 400 ft (122 m) apart. The conductors are often steel-cored aluminium with a cross-sectional area of 0·1 sq in (0·65 sq cm) and have one of several different configurations depending on the supply region and the type of supply. Three commonly used configurations are shown in Fig. 1, and

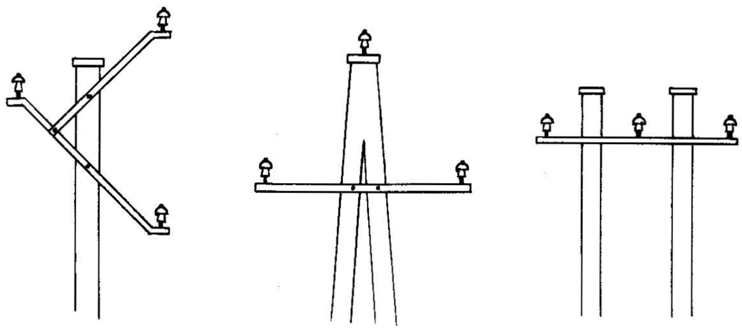

Fig. 1 - Three dispositions of 11 kV 3-phase power-line conductors

three possible ways of energizing the lines for the transmission of v.h.f. signals are illustrated in Fig. 2. In Fig. 2(a) all the overhead wires are connected in parallel at v.h.f., and the v.h.f. generator supplies unbalanced currents between the conductors and earth. In Fig. 2(b) and Fig. 2(c) the v.h.f. generator supplies balanced currents to a pair of the conductors; the third conductor, which is in the neutral plane of the other two, may be earthed to radio frequencies. The unbalanced system of transmission (Fig. 2(a)) has been used for medium-frequency broadcasting in Sweden[1] and Japan,[2] where one of the objects is to supply a useful signal to those areas, very close to the line, where normal broadcasts are degraded by interference from transient currents on the line. The problem at medium frequencies thus differs from that at v.h.f. where complete coverage of an area is required.

As high-voltage lines do not normally have many spurs it is reasonable, in the first instance, to consider the propagation of signals along an unbranched line.

2. PROPAGATION ALONG A LINE CONNECTED AS AN UNBALANCED FEEDER

If the conductors are energized as in Fig. 2(a), currents will flow in the ground and, owing to its finite conductivity, a loss will occur which is proportional to the square root of the frequency. It has been estimated that for an unbalanced line with a characteristic impedance of 250 ohms mounted above ground of conductivity 10^{-2} mho/m, the loss is about 30 dB/km at a frequency of 50 Mc/s. Clearly this attenuation is too high to enable signals to be transmitted over very large distances, unless transmitters of uneconomically high power are used; this method of propagation can therefore be dismissed.

3. PROPAGATION ALONG A LINE CONNECTED AS A BALANCED FEEDER

If two of the conductors of the line are energized by a balanced generator, connected as shown in Fig. 2(b) or Fig. 2(c), the currents which flow in the earth are relatively small. The attenuation is then very much less than when the line is energized as an unbalanced feeder, and it is therefore worth while considering this arrangement in greater detail.

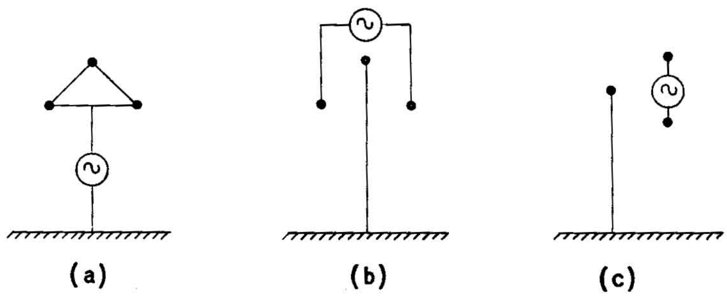

Fig. 2 - Methods of connecting a transmitter to a power line

In any unscreened transmission line, radiation occurs whenever bends, metallic supports or other discontinuities are encountered, but induction fields are always present in the immediate vicinity of the line. The effect of the discontinuities will be considered later; initially the line will be assumed to be uniform, straight and infinitely long.

Before considering the field distribution around such a line, it is useful to consider the field around an infinitely-long, straight, isolated conductor in free space, excited so as to guide an axially symmetrical electromagnetic wave. The velocity of propagation of this wave will depend on the loss in the conductor, and in practice will be slightly less than the free-space velocity. The predominant component of the electric field is that which is polarized radially. Neglecting the time factor $e^{j\omega t}$, for low attenuation it is given approximately by:

$$E_\rho = j\frac{I\eta_0}{4}\ \frac{c}{v}\ \beta\sqrt{1-\frac{c^2}{v^2}}\ H_1^{(1)}\left(\beta\rho\sqrt{1-\frac{c^2}{v^2}}\right)\ e^{-\gamma z} \tag{1}$$

where $Ie^{-\gamma z}$ = the current on the conductor

η_0 = the wave impedance of free space

c = the velocity of light in free space

v = the velocity of propagation along the conductor

β = $2\pi/\lambda$

λ = the free-space wavelength

ρ = the radial distance from the axis of the conductor

γ = the complex propagation constant of the wave in the z direction

z = the distance along the conductor

$H_1^{(1)}$ denotes the Hankel function of the first kind of order unity

Since in practice the velocity of propagation on the conductor is less than the free space velocity, $\beta\rho\sqrt{1 - c^2/v^2}$ is imaginary, and the Hankel function is a negative real quantity for all values of ρ. The phase of E_ρ in the absence of line loss is therefore constant for any given value of z (i.e. in any plane normal to the conductor). In practice there would be a small progressive change in the phase of E_ρ in the radial direction as the wavefront is tilted to compensate for losses in the conductor. This would give rise to a small electric field component parallel to the conductor.

When the attenuation is small, the velocity of propagation is almost equal to the free-space velocity, and equation (1) simplifies to:

$$E_\rho = \frac{I\eta_0}{2\pi\rho} e^{-\gamma z} \tag{2}$$

for all values of ρ which are of interest.

Equations (1) and (2) give the approximate field distribution around a conductor carrying a current $Ie^{-\gamma z}$. The field distribution around a two-wire line above ground may be taken as the sum of the fields due to two such currents and their images in a perfectly-conducting plane. The fields due to the individual currents will still be given by equations (1) and (2), although the propagation constant γ will not necessarily be the same as the value for a single conductor in free-space. The value of γ will depend on the conductor loss, and may be determined by experiment; the velocity of propagation will again be slightly less than the free-space velocity.

The resultant field at the receiving point P shown in Fig. 3, which is at a height h_2 and at a distance d from the centre of the line, is the sum of the fields due to currents in the two parallel conductors and their images in the ground. Since there is no significant change of phase in the radial direction the fields due to the currents in the "go" and "return" conductors tend to cancel each other. An appreciable field is only to be found close to the line, where the magnitudes and directions of the contributions due to the individual lines are significantly different; in this region equation (2) is valid, the contributions to E_ρ due to the two conductors and their images being added vectorially.

When d is large compared with b, h_1, and h_2, but not so large that equation (2) is invalid, it can be shown that:

$$E_\rho \simeq \eta_0 \frac{Ibh_1h_2}{\pi d^4} e^{-\gamma z} \tag{3}$$

where b is the spacing between the conductors of the line. Thus E_ρ decreases as the fourth power of the distance from the line. When d is very large, equations (2) and (3) no longer apply and it can be shown that the field strength at a given height above ground then decreases even more rapidly than the fourth power of the distance from the line. Thus a usable field strength is to be found only in the immediate vicinity of the line.

Fig. 4 gives contours of E_ρ for a typical pair of conductors, fed by a 1 kW 50 Mc/s transmitter. An attenuation of 3 dB/km has been assumed, this value being

extrapolated from measurements made on h.f. two-wire feeders; for this value of attenuation, equation (2) can be used for spacings from the line of up to 800 m. If the line is fed as in Fig. 2(c), the field diminishes even more rapidly in the radial direction. The method of feeding shown in Fig. 2(c) is advantageous if a very small induction field is required; an application is described in Section 6.

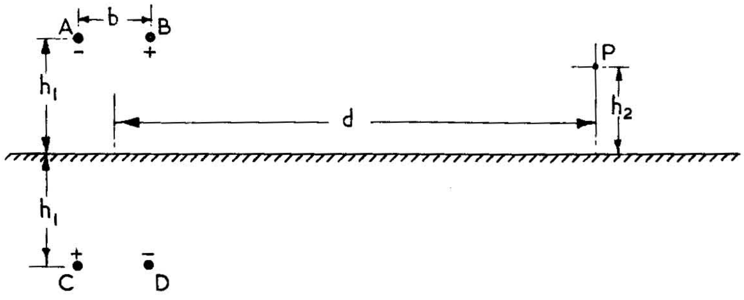

Fig. 3 - A balanced line above a ground plane

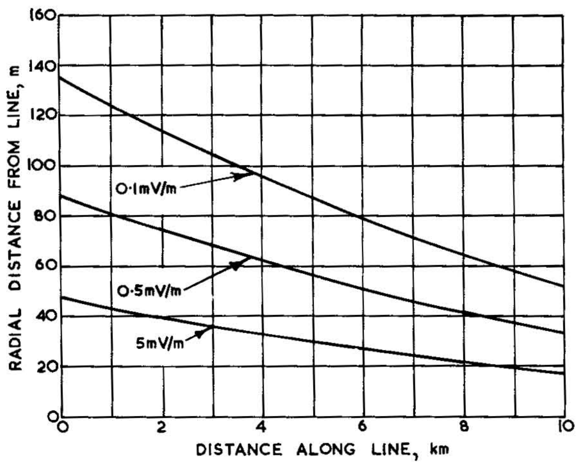

Fig. 4 - Field strength contours near a power line

Conductor spacing 1 m (horizontally)

Line loss 3 dB/km

Height of line above ground 7 m

Height of receiving aerial above ground 9 m

Z_o = 500 ohms

Transmitter power 1 kW

Frequency 50 Mc/s

4. RADIATION DUE TO METAL CROSS ARMS AND OTHER DISCONTINUITIES

So far, only lines which are infinitely long, straight and free from discontinuities have been considered; there is no outward power flow from such lines, and consequently they do not radiate. If the line is of finite length, however, or if bends or other discontinuities are present, some radiation will occur. A receiving aerial coupled to such an idealized line may be considered as a small discontinuity.

In the present application, radiation from the end of the line may be disregarded because of attenuation, unless the line is very short. The bends in power lines are unlikely to be sharp, and it is believed that the resultant radiation will be negligible compared with that occurring at each support pole. Here, currents are induced on the metal cross arms which support the conductors, and radiation therefore takes place. In order to obtain the order of magnitude of the radiated field the idealized line and cross arm shown in Fig. 5 will be considered, for both horizontally- and vertically-spaced conductors.

The lines are taken to be spaced 1 m apart, and to have a characteristic impedance of 500 ohms. The cross arm is taken to be a cylindrical rod having a diameter of 0·01λ, lying in the space between the conductors. It is then assumed that the rod lies in a uniform plane-wave field, of field strength equal to that which exists midway between the lines in the absence of discontinuities. By making these approximations the current in the cross arm, and hence the field which it radiates, may be calculated. The strength of the field radiated by cross arms on horizontally- and vertically-spaced lines are shown in Fig. 6. If there are eight supports per kilometre, the loss due to radiation from the cross arms will be approximately 0·03 dB/km.

The average distance between cross arms is about 120 m, and a receiving aerial will normally pick up signals radiated by a large number of cross arms; these signals will vary in amplitude and arrival time. A curve showing the amplitudes and relative delay times of signals arriving from different cross arms is shown in Fig. 7, for a point situated 1 km from the line. At this distance the maximum field from a horizontal cross arm is picked up from two points on the line which subtend an angle of approximately 55° at the receiving site. In a typical case, over 40

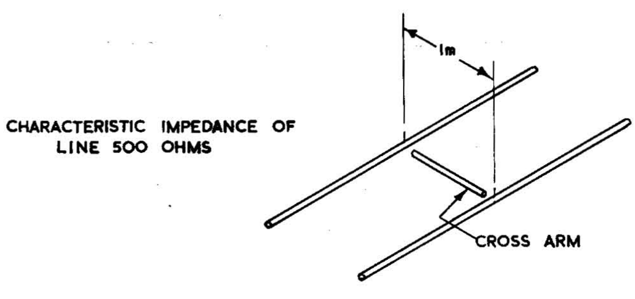

Fig. 5 - The idealized cross arm considered in the calculations

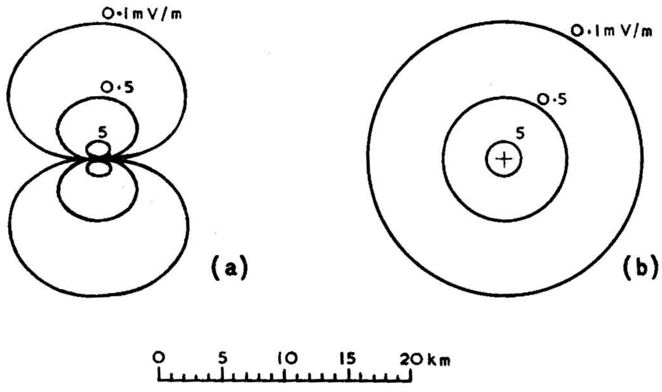

Fig. 6 - Contours of equal field-strength due to radiation by a cross arm

(a) Lines spaced horizontally
(b) Lines spaced vertically

Conductor spacing 1 m
Height of cross arm 7 m
Height of receiving aerial 9 m

Power flow 1 kW
Frequency 50 Mc/s
Z_0 = 500 ohms

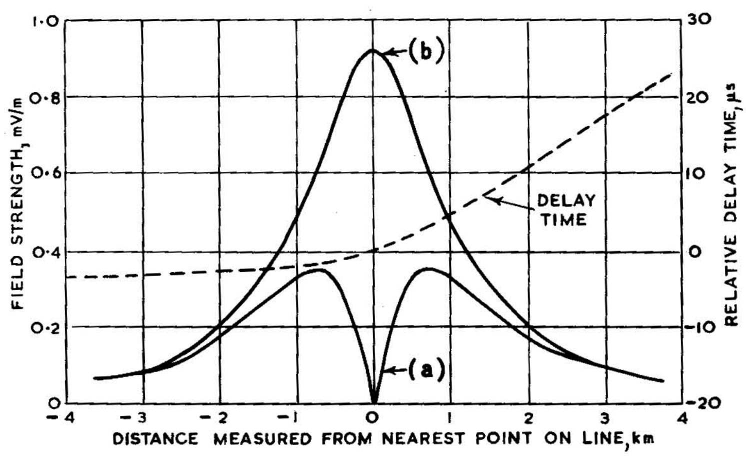

Fig. 7 - Field strength and relative delays of signals received at a point 1 km from the line, due to radiation from cross arms along the line

(a) Horizontally polarized component of field strength from horizontal cross arms

(b) Field strength from vertical cross arms

Dimensions, power and frequency as for Fig. 6

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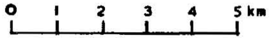

cross arms may make appreciable contributions to the field at a point 1 km from the line, and due to the difference in the arrival times of the contributions the quality of the received picture may be seriously degraded. The degradation could be minimized by using a directional receiving aerial which is arranged to receive signals only from the portion of the line lying in the direction of the transmitter, for which the slope of the delay curve is small. Radiation from a multiplicity of cross arms would give rise to the additional complication of an extremely complex field pattern with deep minima.

5. RADIATION FROM A RESONANT DIPOLE PLACED NEAR TO THE POWER LINES

The cross arms considered in Section 4 were non-resonant, and were therefore inefficient radiators. If it is desired to broadcast to several isolated areas in the vicinity of the power line, but not along the entire length of the line, more efficient radiators could be coupled to the line only at the required points.

More efficient radiation can be achieved by using a resonant half-wavelength dipole, arranged in a plane at right angles to the axis of the power line and parallel to the plane containing the two conductors, as illustrated in Fig. 8. The field re-radiated by the dipole can be calculated by the method described in Section 4. It is found that a 50 Mc/s half-wavelength dipole spaced 0·5 m from the plane containing the line radiates about 0·16 of the power flowing in the line; Fig. 9 gives field-strength contours due to such a dipole at a point where the power flow along the line is 1 kW. A dipole spaced a larger distance away from the line would radiate a smaller fraction of the power flowing in the line.

6. OPTIMUM TRANSMITTING SYSTEM

If continuous coverage along a section of line is required, several dipoles would be spaced at intervals along the line. The signal at the receiving aerial would thus be the sum of the induction field from the line and the radiation from the dipoles and from the cross arms. These contributions to the total field would have different delay times, and television reception would consequently be subject to distortion due to multiple images.

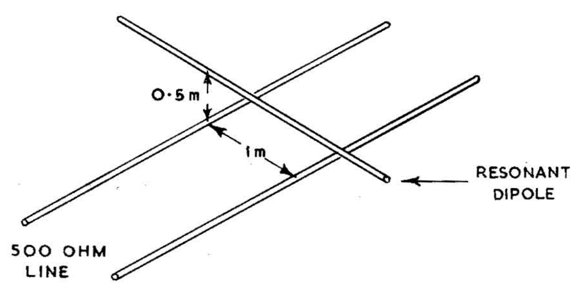

Fig. 8 - Radiating dipole coupled to power line

Reception could be improved by the use of pairs of dipoles spaced about a quarter wavelength apart along the line. The currents in the two dipoles comprising a pair would then differ in phase by 90° and their fields would add and subtract in the forward and backward directions respectively. Signals would be received mainly from dipoles nearer the sending end of the line (the individual contributions would have approximately the same arrival time) with reduced interference from dipoles further forward.

If the configuration of the power line and considerations of co-channel interference allow any choice, multiple image distortion could be still further reduced by feeding a pair of conductors spaced vertically as in Fig. 2(c). The induction field would then be negligible even at small distances from the line, the fields in the nearer regions would be less complicated, and the siting of the receiving aerial would be less critical. Furthermore, an omnidirectional horizontal radiation pattern could easily be obtained, if required, since vertical radiating dipoles could be used.

Even with these modifications to the transmitting system it is unlikely that a high-grade service would be obtained, on account of multiple reflexions. It is thought, however, that the service might be considered acceptable.

7. COMPARISON WITH CONVENTIONAL METHODS OF RADIATION

In assessing the suitability of power lines for v.h.f. broadcasting, the results obtained must be compared with those which would be achieved by conventional

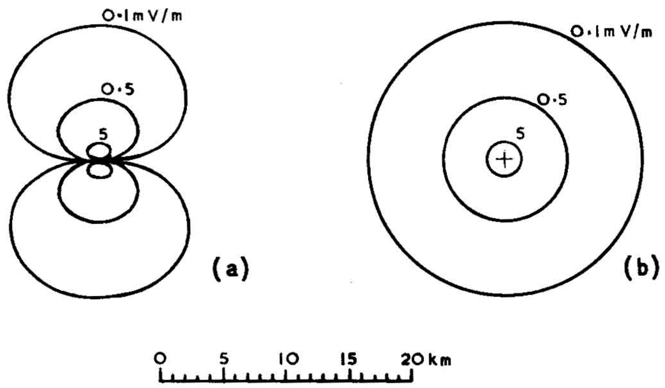

Fig. 9 - Contours of equal field-strength due to radiation from a resonant dipole spaced 0·5 m from a power line

(a) Lines spaced horizontally
(b) Lines spaced vertically

Conductor spacing 1 m
Height of dipole above ground 7 m
Height of receiving aerial above ground 9 m

Frequency 50 Mc/s
Power flow 1 kW
Z_0 = 500 ohms

methods. Since the use of power lines would probably be confined to valleys in hilly country, terrain of this nature will be assumed in making the comparison.

Let us suppose that an area 2 km wide is to be provided with a vertically-polarized signal either by means of a power line fed from a 1 kW transmitter (using the method of feeding shown in Fig. 2(c)), or by a chain of low-power relay stations. If the limit of the service area is defined by the 0 1 mV/m field-strength contour, an adequate signal would be received along the first 7 km of a power line by re-radiation from the cross arms alone. The first vertical dipole coupled to the line would therefore be required at about 8 km from the sending end; dipoles would be subsequently coupled at 2 km intervals to radiate equal powers, until insufficient power was available for providing further service. It may be shown that 16 mW must be radiated by each dipole in order to produce a field strength of 0·1 mV/m (at a height of 9 m) 1 km away from the dipole. For an attenuation of 3 dB/km in the line, the power assumed is only sufficient to feed dipoles up to the 14 km point. The area served by the transmitter is therefore approximately 15 km long and 2 km wide.

Now a simple transmitting aerial consisting of a dipole on a mast 30 m high, fed with a power of 100 W, would produce a field strength (9 m above ground level) of 0·1 mV/m at a distance of 20 km. Thus a greater field strength could be established over the area served by the power line using one-tenth of the power previously considered, provided a line-of-sight path exists between the transmitter and all parts of the service area. A directional transmitting aerial could, of course, be used to advantage in serving a long narrow area, and this would further reduce the power required for the conventional system. If the area to be served is a valley which is not straight, more than one transmitter might be required, but it is unlikely that more than three would be necessary in a 15 km length. The area could therefore still be served by a conventional system using a smaller total transmitter power. The transmitters actually used would probably be simple translators of less than 10 W output.

In the event of more than one transmitter being required, provision would have to be made for rebroadcast reception between adjacent transmitters, but this is unlikely to cause undue difficulties when they are separated by distances of the order of 5 km. There is, of course, no r.b.r. problem along the length of the service area if a power line is used.

Delayed images caused by discontinuities might be apparent with a power line, but could be minimized by suitable orientation of the receiving aerial, as discussed in Section 4. Delayed images caused by reflexions from the sides of the valley would be stronger with the conventional method of broadcasting, but these could also be reduced with the help of directional receiving aerials. On balance, neither system appears to offer advantages where distortion due to delayed images is concerned. Delayed images would in any case be a more serious problem with television than with sound broadcasting.

8. CONCLUSIONS

There are two ways in which power lines could be used for v.h.f. broadcasting, but the only feasible system in practice would be to radiate from a high-voltage

line and to receive with conventional aerials. The alternative of using the supply cables to feed individual houses is not thought to be practicable.

The main use of v.h.f. broadcasting from power lines would be to serve valleys in mountainous areas, as an alternative to using one or more low-power relay stations. The principle advantage of the power line method would be that it would simplify the problem of achieving satisfactory r.b.r. reception. But this technique, in view of the total transmitter power used, and the complexity of equipment involved, might compare unfavourably with the more orthodox practice of using relay stations.

The use of radiation from power lines cannot however be dismissed as impractical, and it would be advisable to carry out experiments to check the theoretical conclusions contained in this report when time permits.

9. REFERENCES

1. Åkerlind, P., "Broadcasting along Power Lines", Tele (Stockholm) No.1, p. 43-50, 1954.

2. "Radio Distribution over Electricity Supply Wiring", E.B.U. Review, Part A, No. 63, p. 226-227, October 1960.